# ENERGISE Program Kickoff

**DOE Award #: DE-EE0007998**

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy


## Scalable/Secure Cooperative Algorithms and Framework for Extremely-high Penetration Solar Integration (SolarExPert)


**University of Central Florida**



October 11, 2017

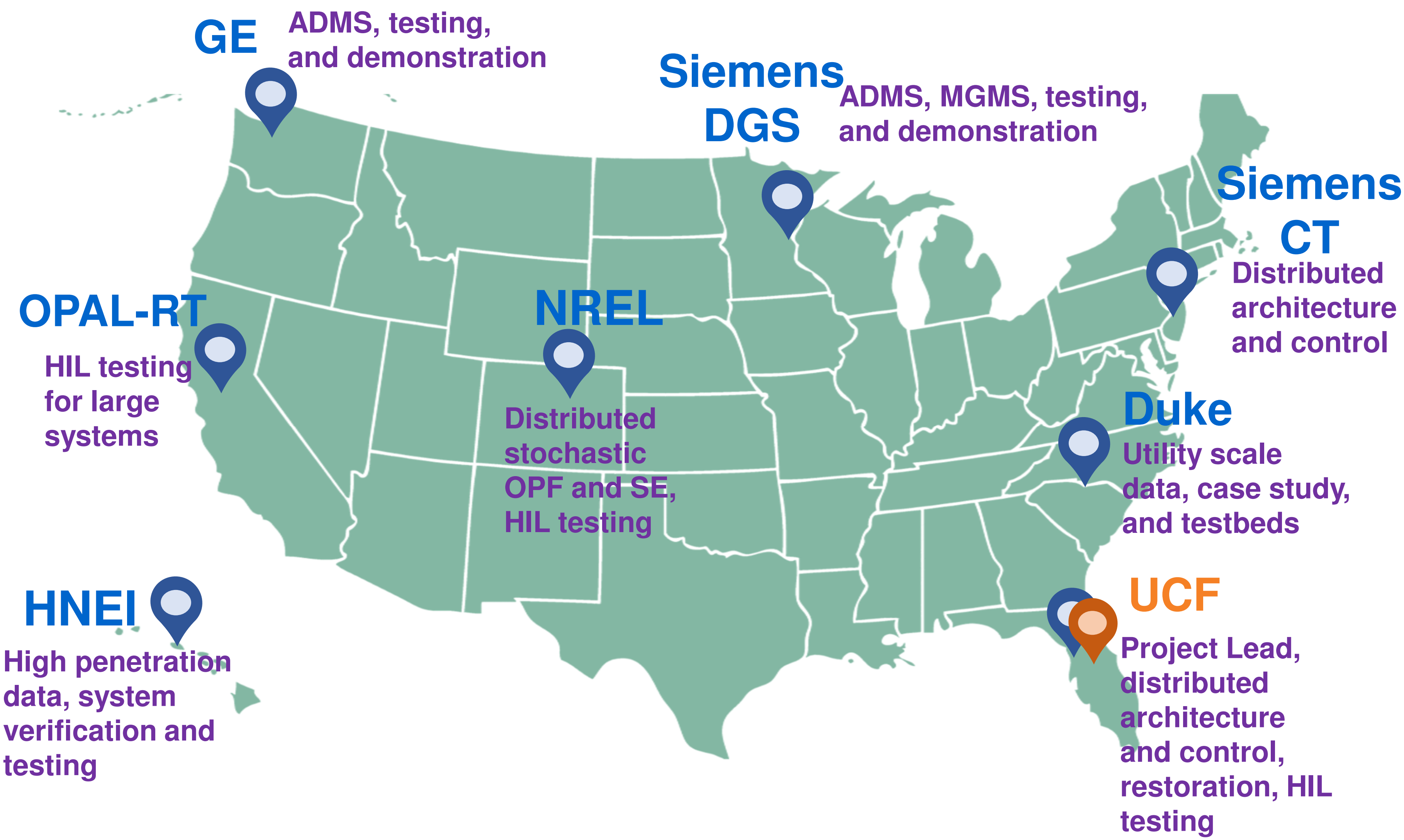
# Project Team

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

| Name | Role | Main Responsibilities (High level tasks/sub-tasks) |
|---|---|---|
| Zhihua Qu (UCF) | PI | Project lead, distributed architecture, distributed voltage and frequency control |
| Wei Sun (UCF) | Co-PI | UCF coordinator, distributed architecture, distributed service restoration |
| Aleksandar Dimitrovski (UCF) | Co-PI | Distribution system protection, distributed voltage and frequency control |
| Qun Zhou (UCF) | Co-PI | Distributed stochastic OPF, distributed system state estimation (DSSE) |
| Robert Reedy (UCF) | Co-PI | Solar integration, testing, and demonstration |
| Benjamin Kroposki (NREL) | Subcontractor | NREL team lead, solar integration |
| Emiliano Dall'Anese (NREL) | Subcontractor | NREL coordinator, distributed stochastic OPF, distributed DSSE, HIL testing |
| Changhong Zhao (NREL) | Subcontractor | Distributed architecture, distributed OPF and voltage and frequency control |
| Leon Roose (HNEI) | Subcontractor | HNEI team lead, high penetration data, system verification |
| Staci Sadoyama (HNEI) | Subcontractor | System validation and testing |
| Ulrich Munz (Siemens CT) | Subcontractor | Distributed architecture, distributed voltage and frequency control |
| Ravinder Venugopal (OPAL-RT) | Subcontractor | OPAL-RT team lead, coordinate the HIL testing for large systems |
| Avnaesh Jayantilal (GE) | Subcontractor | ADMS, testing, and demonstration |
| George Gurlaski (Duke) | Vendor | Utility scale data, case study, testbeds and field tests |
| Clark Wiedetz (Siemens DGS) | Vendor | ADMS, MGMS, testing, and demonstration |

# Map of Project Team

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



# Project Goals



- Meet the long-term goal of ENERGISE by designing highly scalable technologies for distribution systems to operate reliably and securely with extremely high penetration of distributed energy resources.

- The overall project goals are:

  I. design a modular, plug-and-play, and scalable **Sustainable Grid Platform (SGP)** for real-time operation and control of the large-scale distribution network (*>1 million nodes system*);

  II. develop **advanced distribution operation and control functions** to manage extremely high penetration *(>100% of distribution peak load*) solar generation in a cost-effective, secure, and reliable manner.

# Project Objectives

## ENERGISE – SolarExPert

Scalable Sustainable Grid Platform for One Million Nodes Network + Real-time Operation of Extremely High Penetration Solar Generation

### Advanced Grid Architecture

- Distributed Control
- Distributed Optimization
- Adaptive Protection

### Advanced DMS Functions

- Distributed Volt/VAR and Frequency Control
- Distribution System Restoration

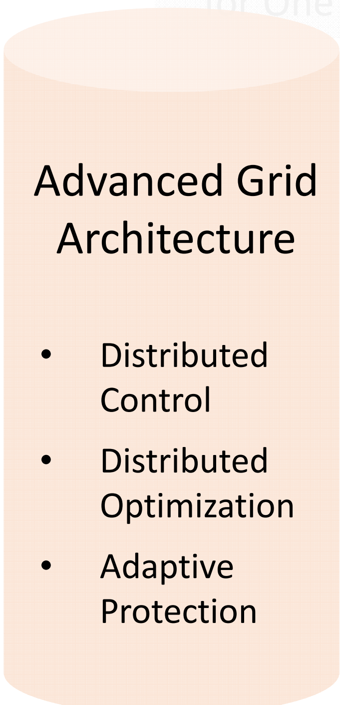
### Enhanced System Layers

- Distributed Stochastic OPF
- Distributed Distribution System State Estimation

### Testing and Demonstration

- Software Simulation
- Hardware-in-the-loop Testing
- Testbed Validation

# Major Innovation I




❖ The proposed **distributed control and optimization** are plug-and-play, automated, real-time, and scalable.

- To enable heterogeneous intelligent devices such as PV inverters, energy storage, electric vehicles (EVs), etc. to dynamically contribute to demand responses and ancillary services and seamlessly coordinate with the DMS.
- To work with a variety of communication layers, ensure operational performance under variable communication topologies and various frequencies, and maintain stable operation for high PV penetration.

# Major Innovations II & III

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Advanced DMS Functions

- Distributed Volt/VAR and Frequency Control
- Distribution System Restoration

❖ The **scalable voltage and frequency control and optimization framework** allow an unlimited number heterogeneous devices to

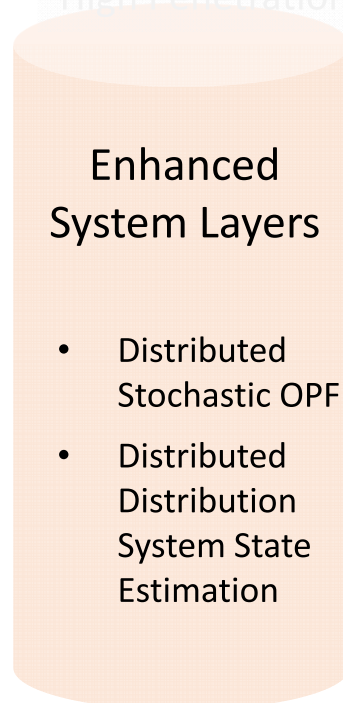
- locally interact with each other;
- implement low-complexity distributed algorithms at different time scales;
- interface cooperatively with DMS or by forming self-organizing microgrids.

❖ The **distribution restoration strategy** based on distributed cooperative control and optimization greatly enhance the traditional system layer.

- It also seamless interaction of DMS with OMS and DERMS and integration of measurement, estimation, control and security components.

❖ The developed **online distributed stochastic OPF** enables the adaptive operation by using real-time measurements.

- It enables predictive and prescriptive controls for real-time and operational planning.
- The control algorithms are generalized from single-phase to multi-phase unbalanced power flow models.
- Stochastic analysis and optimization tools are applied to predict power system behaviors, including the hosting capacity, flexible loads and storage.



# Major Innovation V



❖ The multi-step testing and demonstration plan

- Software modeling and simulation (UCF campus system and data)
- HIL testing and validation (NREL Energy Systems Integration Facility, P-HIL and C-HIL test bed)
- Experimentation through testbeds (vendor – GE and Siemens DMS, ADMS, DRMS, MGMS; utility – Duke and HENI distribution network)

**Testing and Demonstration**

- Software Simulation
- Hardware-in-the-loop Testing
- Testbed Validation

# Task 1 (Subtasks) & Milestone 1

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **Task 1 – Design System Architecture of Distributed Control and Optimization**

ST 1.1-Select simulation engine(s)

ST 1.2-Design system architecture

ST 1.3-Develop DG clustering and self-organizing strategies

ST 1.4-Aggregate clusters and develop cooperation control algorithms

ST 1.5-Collect test system data

ST 1.6-Test the architecture in software simulation

ST 1.7-Consult with the industry partner of ADMS vendors and utilities

ST 1.8-Collect requirements of integrating the modules of DMS with vendors' software solutions

ST 1.9-Submit code, document of developed models and algorithms, and testing report to DOE

**BP 1**
10,000-node system

**BP 2**
100,000-node system

**BP 3**
1,000,000-node system

**Advanced Models and Parallel Computing**

**Software Simulation, HIL Testing, and Real-World Network Validation**

- **Milestone 1 –** Response time for all test systems at the local level is < 10 secs, at the network level is < 30 secs and at system level is < 1 min; accuracy is no more than 1% different from centralized approaches; and DOE and industry buy-in the developed system architecture

# Task 2 (Subtasks) & Milestone 2



## ❖ Task 2 – Develop the Distributed Optimal Power Flow (DOPF)

ST 2.1-Collect test system data

ST 2.2-Decompose into subproblems

ST 2.3-Extend to three-phase unbalanced distribution systems

ST 2.4-Develop the stochastic version of DOPF (DSOPF)

ST 2.5-Test the DOPF and DSOPF in software simulation

ST 2.6-Perform techno-economic analysis to run DSOPF in large-scale distribution networks

ST 2.7-Submit code, document of developed models and algorithms, and testing report to DOE

**BP 1**
10,000-node system

**BP 2**
100,000-node system

**BP 3**
1,000,000-node system

**Advanced Models and Parallel Computing**

**Software Simulation, HIL Testing, and Real-World Network Validation**

❖ **Milestone 2 –** DOPF convergence of < 1 min for real-time operation and < 5 min for planning, and the objective function value is no more than 1% different from the DOPF solutions

# Task 3 (Subtasks) & Milestone 3

- **Task 3 – Develop Distributed Distribution System State Estimation (DDSSE)**

ST 3.1-Collect test system data

ST 3.2-apply prediction-correction methods and update the estimates of system states in real time

ST 3.3-Implement the online-capable DDSSE

ST 3.4-Examine stability and performance of online DDSSE

ST 3.5-Test DDSSE in software simulation

ST 3.6-Perform techno-economic analysis to run DDSSE in large-scale distribution networks

ST 3.7-Submit code, document of developed models and algorithms, and testing report to DOE

**BP 1**
10,000-node system

**BP 2**
100,000-node system

**BP 3**
1,000,000-node system

**Advanced Models and Parallel Computing**

**Software Simulation, HIL Testing, and Real-World Network Validation**

- **Milestone 3 –** DDSSE observability >99%, accuracy <5% error compared to the true value, and convergence time <1-10 seconds

## ❖ Task 4 – Develop Distributed Voltage and Frequency Control

ST 4.1-Collect load and DG data

ST 4.2-Develop the algorithms and also for islanded distribution grid

ST 4.3-Collect sample profiles of negative load control, storage and demand responses

ST 4.4-Test the algorithms in software simulation

ST 4.5-Perform techno-economic analysis to run algorithms in large-scale distribution networks

ST 4.6-Devise a plan for developing and implementing algorithms in Florida and Hawaii

ST 4.7-Submit code, document of developed models and algorithms, and testing report to DOE

**BP 1**
10,000-node system

**BP 2**
100,000-node system

**BP 3**
1,000,000-node system

**Advanced Models and Parallel Computing**

**Software Simulation, HIL Testing, and Real-World Network Validation**

❖ **Milestone 4 –** the algorithm produces a uniform voltage profile and frequency recovery after disturbance

# Task 5 (Subtasks) & Milestone 5

## ❖ Task 5 – Develop Distributed Service Restoration (DSR)

ST 5.1-Formulate a centralized service restoration benchmark

ST 5.2-Develop distributed service restoration algorithm based on distributed cooperative control of multi-agent systems

ST 5.3-Test DSR in software simulation

ST 5.4-Perform techno-economic analysis to run DSR in large-scale distribution networks

ST 5.5-Submit code, document of developed models and algorithms, and testing report to DOE

**BP 1**
10,000-node system

**BP 2**
100,000-node system

**BP 3**
1,000,000-node system

**Advanced Models and Parallel Computing**

**Software Simulation, HIL Testing, and Real-World Network Validation**

❖ **Milestone 5 –** DSR convergence to the centralized service restoration benchmark

# Task 6 (Subtasks) & Milestone 6



## ❖ Task 6 – Enhance Simulation Capability by Advanced Models and Parallel Computing

ST 6.1-Develop advanced memory allocation methods

ST 6.2-Develop a novel parallel computing method

ST 6.3-HIL testing and validation

ST 6.4-Test various DMS functions using the parallel computing algorithms in software simulation

ST 6.5-Perform techno-economic analysis to test developed algorithms in large-scale distribution networks

ST 6.6-Submit code, document of developed models and algorithms, and testing report to DOE

**BP 1** – 10,000-node system → **BP 2** – 100,000-node system → **BP 3** – 1,000,000-node system

**Advanced Models and Parallel Computing**

**Software Simulation, HIL Testing, and Real-World Network Validation**

❖ **Milestone 6 –** 1) steady-state values of voltages and currents at a set of chosen nodes compared with the quasi-static load flow values from standard distribution simulator, within a range of 0.5% for magnitudes and 0.5 degree for angles and 2) HIL response time under 5 seconds

# Task 7 (Subtasks) & Milestone 7



## ❖ Task 7 – Integration and Testing

ST 7.1-Conduct software modeling and simulation using real world data

ST 7.2-Validation through real-world distribution networks

ST 7.3-Integration of DMS functions

ST 7.4-Testing using real-world distribution networks

ST 7.5-Perform techno-economic analysis to commercialize algorithms in large-scale distribution networks

ST 7.6-Submit code, document of developed models and algorithms, and testing report to DOE

**BP 1**
10,000-node system

**BP 2**
100,000-node system

**BP 3**
1,000,000-node system

**Advanced Models and Parallel Computing**

**Software Simulation, HIL Testing, and Real-World Network Validation**

❖ **Milestone 7 – Integrate and Test various DMS functions in SGP using the integrated distribution system simulator platform** the success value of 1) M1 for system architecture, 2) M2 for DSOPF, 3) M3 for DDSSE, 4) M4 for voltage and frequency control, 5) M5 for DSR, and 6) M6 for HIL

# Project Milestones: Decision Points

- **Go/No-Go Decision Point**: Successful completion of all milestones throughout the budget period. The distributed architecture and various DMS functions should satisfy the following criteria for 1,000-node, 10,000-node, 100,000-node, and 1,000,000-node systems:

  1) Computational cycle of Sustainable Grid Platform (e.g., DOPF) should be <1 minute for real-time operation and <5 minutes for operational planning; accuracy is no more than 1% different from centralized approaches;
  2) Response time of the multi-level control (e.g., distributed voltage and frequency control) should be <10 seconds for local level, <30 seconds for network level, and <1 minute for system level;
  3) DDSSE is successfully solved with system observability >99%; accuracy <5% error compared to the true value, and convergence time <1-10 seconds; and
  4) System architecture design get buy-in from DOE, the industry, and utilities

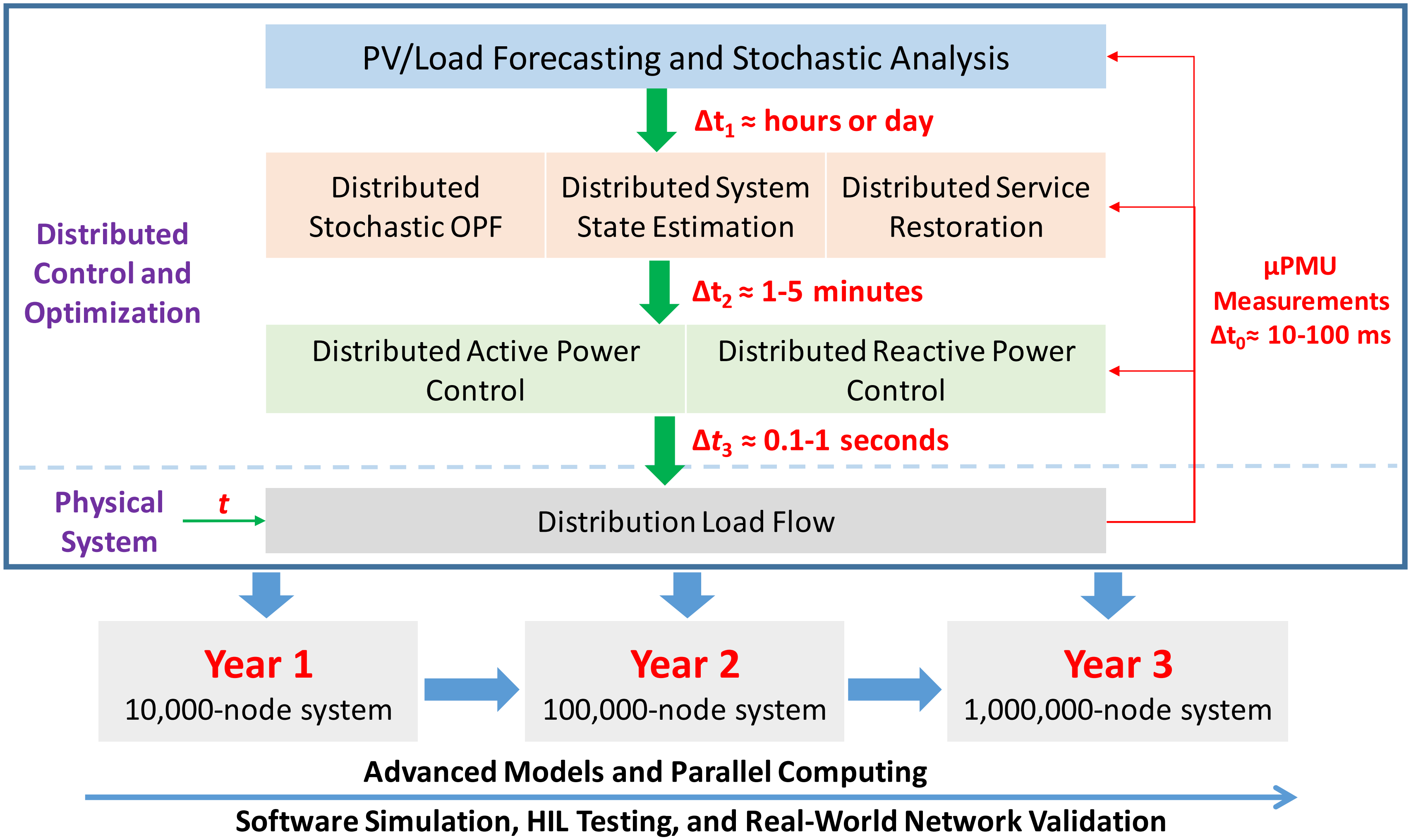
# Project Deliverables

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

1) **Open source software** of the *Sustainable Grid Platform* with scalable architecture of distributed control and optimization
2) Documents of **developed models and algorithms** – Advanced DMS functions
   - *online distributed stochastic optimal power flow* based on dynamic, real-time, distributed feedback control;
   - *online distributed system state estimation* algorithms based on prediction-correction methods for time-varying convex optimization;
   - *distributed volt/VAR optimization and frequency control* algorithms based on distributed cooperative control and optimization;
   - *distribution system restoration* strategy based on distributed cooperative control of multi-agent systems;
3) Documents of **software simulation results**;
4) Documents of **HIL testing procedure and results**;
5) Published **journal and conference papers, presentations**.

# Project Architecture

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



# High Risks & Mitigation



- ❖ The proposed distributed control and optimization haven't been integrated for large-scale distribution network.
  - The distributed, multilevel, scalable approach proposed in this project is inherently robust by design and scalable by nature.
  - Simulation will be performed step-by-step in different sizes of distribution systems throughout three budget periods.

- ❖ There are no available software or hardware simulation tools available to test the proposed models and algorithms
  - Develop our own software tools using open-source software (OpenDSS, OpenFMB, etc.)
  - Leverage existing hardware testbeds (NREL HIL testbeds) for testing and validation

# Cybersecurity & Interoperability

- The SolarExPert team will develop and submit a **cybersecurity** plan that incorporates open standards on information exchange between networks, systems, devices and application.
  - By working with industry and utility partners, interface design will be done to ensure confidentiality, integrity and availability of data and their communication.

- The SolarExPert team will establish **interoperability** by building plug-and-play features into the proposed SGP and embedding open source software and open standards.
  - Implement the proposed models and algorithms using open source software (OpenDSS), and develop the scalable distributed architecture conforming to industrial standards-based platform (OpenFMB)

# Question?

# Thanks